Useful reactions

K_0 regeneration

$K_L \xrightarrow{\text{also } P (2\pi \text{ violate } CP)} 3\pi \ (CP=-1)$

$K_S \to 2\pi \ (CP=+1)$

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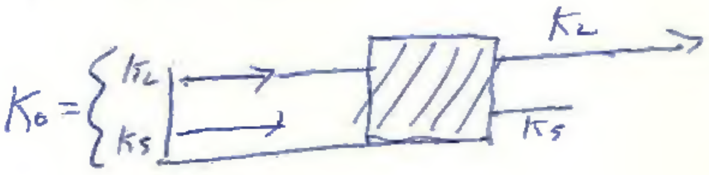
$CP(K_0) = -\overline{K_0}$

$CP(\overline{K_0}) = -K_0$

$K_L = \frac{1}{\sqrt{2}}(K_0 + \overline{K_0})$

$K_S = \frac{1}{\sqrt{2}}(K_0 - \overline{K_0})$

$\overline{K}^0 + p = \Lambda^0 + \pi^+$



produced in $\pi^- + p = \Lambda^0 + K_0$.

$\overline{K_0}$ produced in $\pi^+ + p = K^+ + \overline{K_0} + p$.

neutrino reactions ① $\bar{\nu}_e + p = n + e^+$ (Reines, Cowan) (inverse $n \to p + e^- + \bar{\nu}_e$)

② $\nu_\mu + n = \mu^- + p$ (Lederman discovery)

but not $\nu_\mu + n = e^- + p$.

③ $\nu_\mu + \cancel{p}\, n = \nu_\mu + \text{hadrons}$ (neutral currents)

$K_0 \to \mu^+ + \mu^-$ forbidden.

cf Weinberg (1967) – Salam (1968) unification e.m. & weak. ($2 W$'s, charged & neutral, asymptotic vacuum) cf $e^+ + p = e^+ + p$ and $n \to p + e^- + \bar{\nu}$

Resonances $\pi + N \to N^* \to \pi + N$ (Fermi – reaction for 1st large resonance)

$\pi + N \to \rho + N \to \pi + \pi + N$ (ρ-meson discovery)

antiproton $p + p \to p + p + p + \bar{p}$

Associated production (Pais 1952)

Λ^0 decay $\Lambda^0_{-1} \to \cancel{n + \pi^0}\ p + \pi^-_0$ S

$\pi^+_0 + n_0 \to \Lambda^0_{-1} + K^+_{+1}$ S

pion decay $\pi \xrightarrow{\text{strong}} N + \bar{N} \xrightarrow{\text{weak}} \mu + \nu$

P.T.O.

weak-interaction coupling

axial vector coupling constant

$$H = G\left[\left(\bar{\psi}_p \gamma_\mu \left(C_V + \gamma_5 C_A\right) \psi_n\right)\left(\bar{\psi}_e \gamma_\mu \left(1+\gamma_5\right) \psi_\nu\right)\right]$$

$$J = J_A + J_V$$

$$H' = \int \underset{\sim}{J}(x) \cdot \underset{\sim}{J}^{+}(x)\, d^3(x)$$

In general $J = J_L + J_B$ $\left\{\begin{array}{l} J \cdot J \to J_L^2 \text{ leptonic} \\ J_L \cdot J_B \text{ semi-leptonic} \\ J_B^2 \text{ non-leptonic} \end{array}\right.$

$$C_A = +1.25\, C_V$$

experiment confirmed by theory.

renormalize axial vector coupling constant

w-particle lower bound on mass → 4.4 GeV, May 73

Tachyon proposed 1962 by Bilaniuk, Deshpande & Sudarshan.
named by ~~G~~ Feinberg in 1967 $\left\{\begin{array}{l} \text{Tardons} < c \\ \text{Luxons} = c \\ \text{Tachyons} > c \end{array}\right.$

$$\text{Mass} = i\, m_0$$

$$E = \frac{m_0 c^2}{\sqrt{v^2/c^2 - 1}}.$$

Discovery of Ω^-

$$K^- + p \to \Omega^- + K^+ + K^0$$

$\Omega^- \to \Xi^0 + \pi^-$

$\Xi^0 \to \Lambda^0 + \pi^0$

$\Lambda^0 \to \pi^- + p$

$\pi^0 \to \gamma + \gamma$; $\gamma \to e^+ + e^-$; $\gamma \to e^+ + e^-$

12 acts

Beam energies

28 gev	CERN	1960	
7 gev.	Rutherford	1963	(Nimrod)
33 gev	Brookhaven	1960	
70 gev	Serpukhov	1967	
200–500 gev.	N.A.L. Batavia, Illinois		(1972) → 400 gev
300 gev.	CERN.		

Storage rings

25 gev p.p.	CERN	1971
0.55 e^+e^-	Orsay	1967
0.5 e^+e^-	Stanford	1966
0.7 e^+e^-	Novosibirsk	1966

(Berkeley)
→ Bevatron 1954, 6.2 gev of which a 6 gev beam to produce an anti proton
experiment carried out in 1955
by Chamberlain, Segré, Wiegand
& Ypsilantis
Cosmotron 1953 1.4 gev (Brookhaven)

Usefull numerical results

1 Fermi $= 10^{-13}$ cm $\qquad$ 1 mb $= 10^{-27}$ cm^2

radius hydrogen atom $= e^2/mc^2 \cdot \alpha^{-2} \simeq \hbar^2/e^2 m = 0.5 \times 10^{-8}$ cm

Compton wavelength $= e^2/mc^2 \cdot \alpha^{-1} \simeq \hbar/mc \simeq 0.4 \times 10^{-10}$ cm

radius of electron $= e^2/mc^2 \simeq 0.3 \times 10^{-12}$ cm

range for pion is 1.4 Fermi

10^{-13} cm $\equiv$ 200 Mev particle

10^{-23} sec $\equiv$ 65 Mev resonance width

$(\text{Gev})^{-2} \equiv 0.4$ mb

Experimentally range nuclear forces is $\sim 2 \times 10^{-13}$ cm
$\equiv$ 100 Mev mass

$(1-2 \times 10^{-13}$ cm $\equiv$ 100 — 200 Mev particle$)$

C.m energies $\quad E^{\text{Total}}_{\text{c.m.}} = \sqrt{2 E_{\text{lab}}}$ in gev.

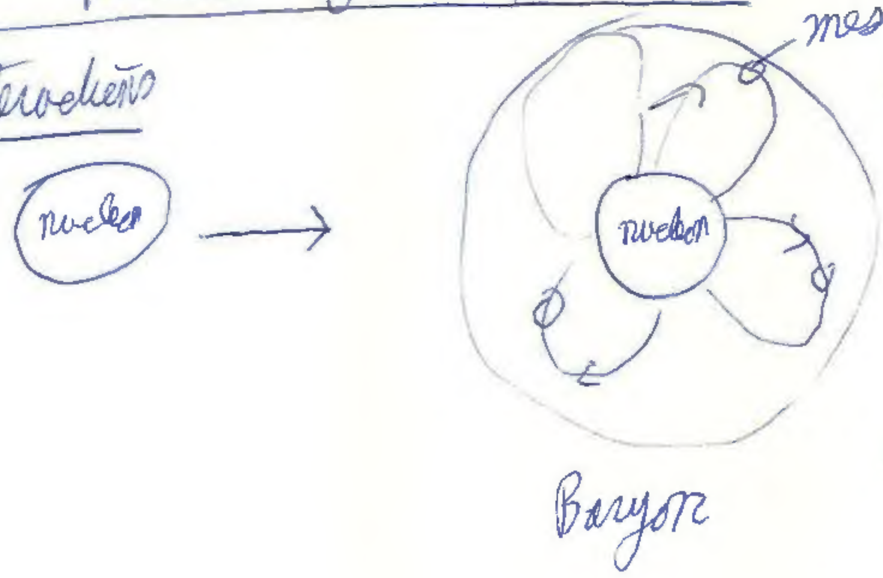
In colliding beams $\quad E^{\text{Total}} = 2 E_{\text{lab}}$

$\left\{ \begin{array}{l} \text{30 gev beam} \to \text{8 gev available} \\ \text{200} \quad , \quad \to \text{20 gev available} \\ \qquad \text{for production.} \end{array} \right.$

P.T.O

Simple picture of the particles

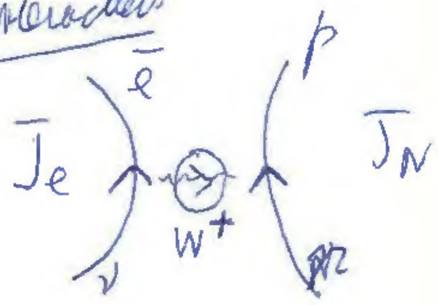
Strong Interactions



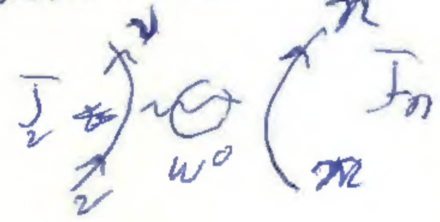
(pions for $N^*(1236)$ etc
kaons for Λ^0 etc.

Model
strong-coupling
theory of
meson-fields
Pauli 1946
Meson Theory of Nuclear Forces.
(but note problem
of strangeness
Λ^0 involves K meson.)

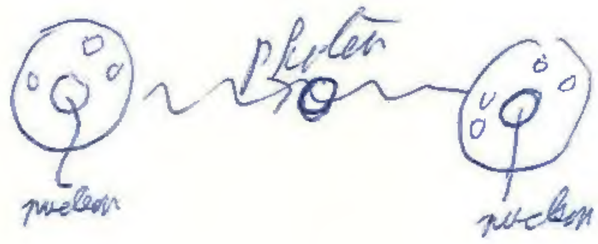
Weak interactions



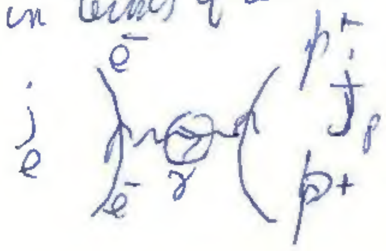
or neutral currents



e.m Interactions

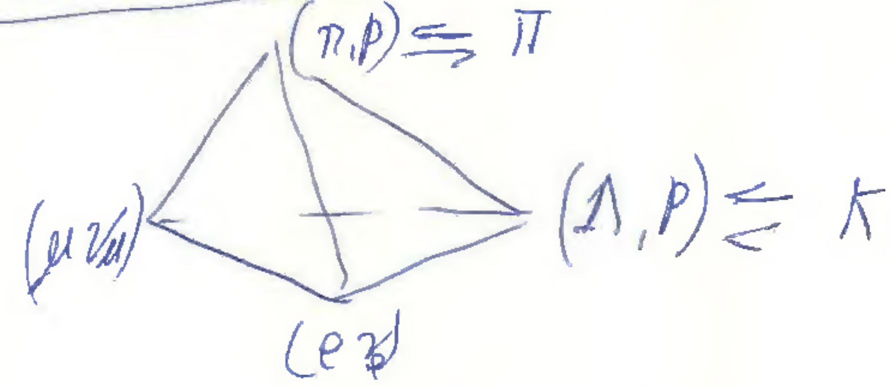


or in terms of currents



P.T.O

Gell-Mann Puppi tetrahedron



then $\Lambda_0 \xrightarrow{\text{weak.}} \cancel{p} \; N + \underbrace{N + \bar{N}}_{\xrightarrow{\text{strong}} \pi}$

$K \xrightarrow{\text{strong}} \Lambda\, p \xrightarrow{\text{weak}} N\, N \xrightarrow{\text{strong}} \pi + \pi +$

$\Lambda \rightarrow N + K$ not energetically possible

Associated production

$\pi^+ + n = \Lambda^0 + K^+$

Interpretation of coupling constant (cf. Fermi) (14)

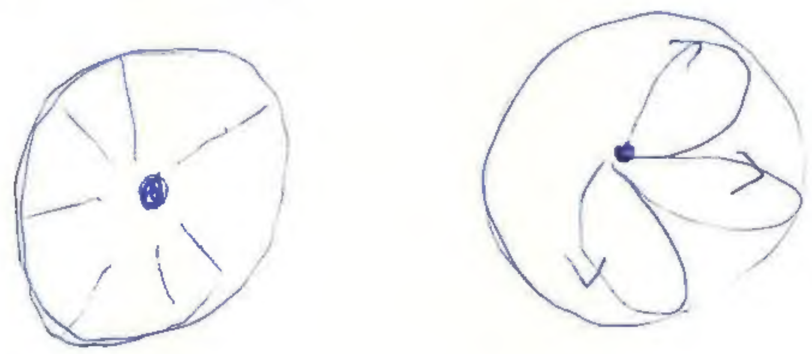
Interaction parameter such as $e^2/\hbar c$

measures: mean $n^{\underline{o}}$ of particles of type II

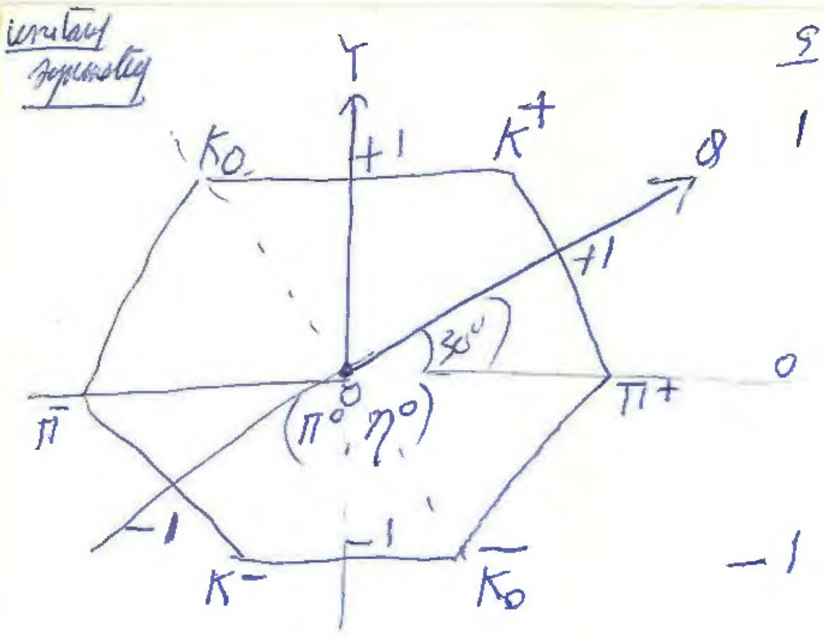
surrounding particle of type I.

For $\psi = \psi_I + \sum_n \psi_{I + n\,II} \cdots$

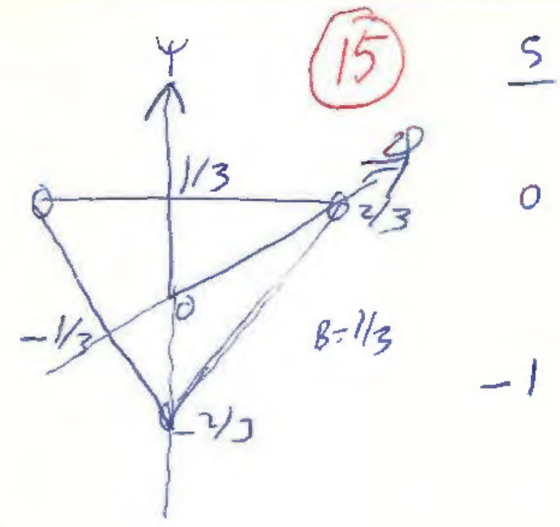
$$\bar{n} \sim e^2/\hbar c$$



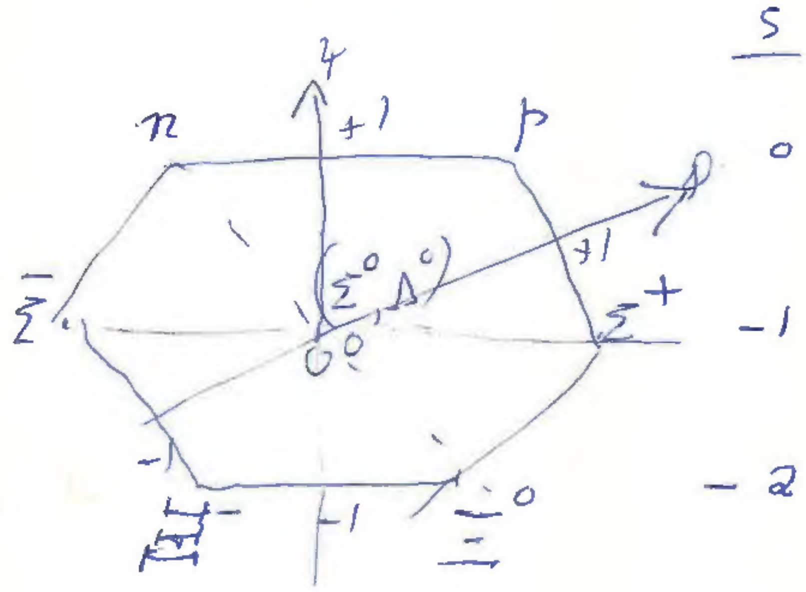
unitary symmetry



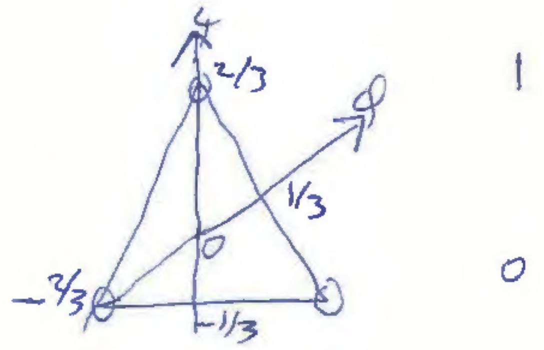
mesons



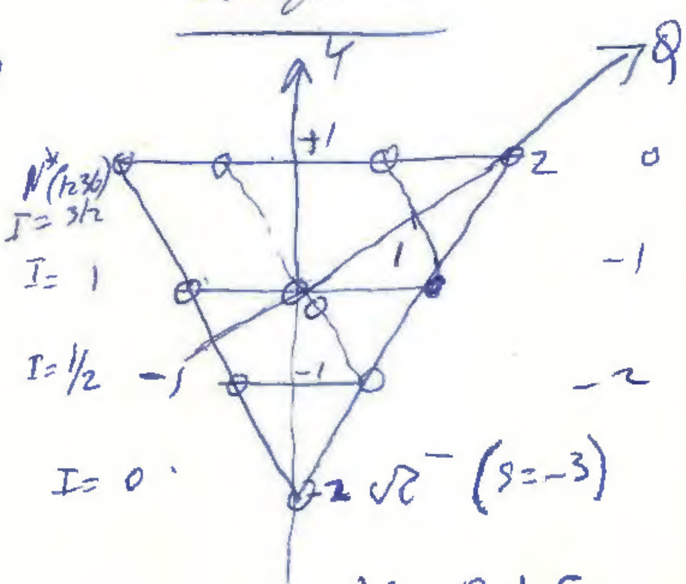
quarks



baryons



antiquarks



mesons $3 \times 3^* = 8 \oplus 1$

baryons $3 \times 3 \times 3 = 10 \oplus 8 \oplus 8 \oplus 1$

$Y = B + S$

$Q = \frac{1}{2} Y + T_3$

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Range - energy relation

$\Delta E = mc^2$

$\Delta t = \hbar / mc^2$

distance travelled $< c\,\Delta t = \hbar / mc$

maximum range is $\hbar / mc$.

photon

~~classical~~ wave (classical) $\xrightarrow{\text{field quantization}}$ particles (photons) N — quantized wave $\Downarrow$ N particles (quantized)

$\downarrow$

Heisenberg, Pauli 1929

electron

{quantized particle (electrons) N $\xrightarrow{2^{nd}\ \text{quantization}}$ quantized wave} (matter field $\equiv$ 1 particle S. Eqn.)

Jordan, Klein
Jordan, Wigner

$\downarrow$

Fock 1932.

equivalence sets of oscillators
$\supset$ set of particles alike

for Dirac 1927
Jordan, Klein ~~Pauli~~ ~~1928~~ 1927
↳ fermions Jordan, Wigner 1928

N classical particles $\xrightarrow{\text{1st quantization}}$ N ~~quantized~~ particles Schrödinger Eqn $\overset{2^{nd}\ \text{quantization}}{\underset{\text{equiv.}}{\Rrightarrow}}$ quantized field (set of quantum oscillators)

(1927) Dirac (photons)?
(1927) Jordan, Klein (Bosons N.R.)
(1928) Jordan, Wigner (Fermions N.R.)

classical field $\xrightarrow{\text{field quantization}}$ quantized field (set of Q. oscillators) $\Rrightarrow$ N particle Schrod Eqn

(1928) Jordan, Pauli
(1929, 1930) Heisenberg, Pauli
[(1934) Pauli, Weisskopf (charged scalar field)]

Scattering of delocalized Ion

$$\theta \sim me/p$$

$$\Delta\theta \sim \lambda/D = \frac{\hbar}{pD} \Rightarrow \frac{me}{p} = \theta.$$

But $D \ll \hbar/me$

forward peak $\sim \dfrac{1}{q^2+m^2} = \dfrac{1}{p^2\sin^2\frac{1}{2}\theta + m^2}$

peak at $\Delta\theta$ seen $\sim$

$p\Delta\theta \sim m \quad \Delta\theta \sim m/p$

(20)

<u>the paraquark</u>

$$d\sigma \sim \left| \int e^{-i k' \cdot r}\, V(r)\, e^{i k \cdot r}\, dr \right|^2$$

$$\sim \quad V^2(q) = \rho^2(q) \frac{1}{q^4} \Big/ q \text{ is momentum transfer}$$

$$q = 2 k \sin^2 \tfrac{1}{2}\theta$$

now $\nabla^2 V \propto \rho$

$$V(r) = \int V(q)\, e^{iqr}\, dr$$

$$\nabla^2 V = \int \underbrace{q^2 V(q)}_{\rho(q)}\, e^{iqr}\, dr \;=\; \rho(r)$$

$$\left(\text{so } V(q) = \rho(q) \cdot \tfrac{1}{q^2}\right)$$

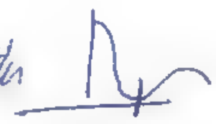
~~$\rho(q)$~~ now $\rho(r) = \int \rho(q)\, e^{iqr}\, dq$

if $\rho(0) = 0$

(by antisymmetry $\psi(r_1 - r_2) = -\psi(r_2 - r_1)$
so $\psi(0) = -\psi(0) = 0$)

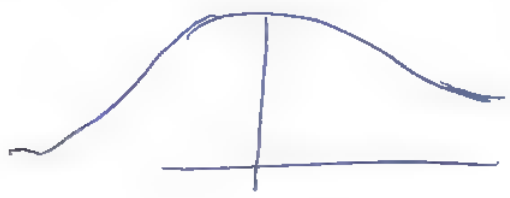
then $\int \rho(q)\, \cancel{e^{iqr}}\, dq = 0$

so $\rho(q)$ has a zero. $\rho^2(q)$ either



not decreased exponentially

(like $\dfrac{1}{1 + q^2/k^2}$)



<u>N.B.</u> X-section $\propto$

Chew, Gell-Mann & Rosenfeld Sci. Am. 210 (2): 74
popular article. (1964)

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Sum Rule

$\langle \psi | (AB - BA) | \psi \rangle = \langle \psi | C | \psi \rangle$

$= \sum_n \left(\langle \psi | A | \phi_n \rangle \langle \phi_n | B | \psi \rangle \right) - \sum_n \left(\qquad \right)$

$= \langle \psi | C | \psi \rangle .$

↳ $\sum_n \left(\phi_n | A | \psi \right)^2$

↳ Sum of transition strengths to ϕ from all states.

Prof

Heisenberg's Unified Field Theory

Universal length arises since 3 constants are needed to establish a system of units e.g. c, $\hbar$ & ℓ

then $m = \dfrac{\hbar}{\ell c}$ gives scale of masses

"Eq. of motion for matter is a quantized non-linear wave equation for a wavefield of operators that simply represents matter, not any specified kind of waves or particles." This wave equation will lead to integral equations with eigensolutions representing the particles. They are the mathematical forms replacing the regular solids of the Pythagoreans.

Eq is: —

$$i\sigma^{\nu}\frac{\partial\chi}{\partial x^{\nu}} + \ell^{2}\sigma^{\nu}\chi\left(\chi^{*}\sigma_{\nu}\chi\right) = 0.$$

χ is a 2-component spinor. , proposed 1959

described in book 1960